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Polarized diffractive optical element design for a multiple-beam optical pickup head

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ABSTRACT

This paper addresses the design and construction of an interesting polarization-switched diffractive optical element (DOE) that generates multiple beams incident on the disk and acts as a beamsplitter and servo-generating element for light returning from the disk. In this way, data speed is increased proportional to the number of beams on the disk, and, by combining three functions into a single optical element, allows a more compact and lightweight pickup to be realized. The polarization-switched DOE is constructed as a sandwich of two pieces of some birefringent material, with one rotated by 90 degrees relative to the other so that the ordinary and extraordinary axes are interchanged, and with a common index-match layer between them. A diffractive pattern is etched into each of the two birefringent pieces. Linearly polarized light travelling from the laser towards the disk is diffracted into multiple beams by one of the diffractive patterns while experiencing no diffraction from the other. Travelling the roundtrip from the DOE to the disk and back to the DOE, the light traverses a quarter-wave retarder two times thereby rotating its polarization direction by 90 degrees. It now experiences no diffraction from the multiple beam diffraction layer, but is diffracted by the second diffraction layer, which steers it onto the photodetectors and alters the beam to create useful focus and tracking error signals. This design is important in that it provides a way for two diffractive surfaces, each acting independently with high efficiency on orthogonal polarizations of light, to be combined into a single element. Implementation and application to a multiple-beam holographic pickup head module are presented.

Keywords: Diffractive Optical Element, Holographic Optical Element, Optical Pickup Head, Multiple-Beam Pickup Head

1. INTRODUCTION

In these years, optical drive market has prosperously grown. CD-ROMs have become standard peripheral equipment for computer hardware. With each new generation of disk drives, optical storage system designers face tougher challenges to cut margin, reduce size and weight, and increase data speeds. The challenges, translated to the pickup-head level, lead the designer to multiplex several functions into a single optical element and devise techniques to increase data speed.

CD-ROM drive data transfer rates increased phenomenally from 1X in 1991 to 50X in 1999. The CD-ROM drive market today allows for a maximum speed of 50X under constant angular velocity (CAV) motor control, but only on the outermost tracks. Data read from the inner tracks of a disk is only read at a mere 20-25X. High speed CD-ROM drives make noisy vibration induced from high speed spindle motor operation and run the risk of ruining the disks. There has been a significant amount of negative performance for these high-speed drives.

Most CD-ROM drives use an optical head with a single laser beam for sequential data access. The laser beam is directed at a single track of information that forms a continuous spiral on the disc. The disk drive rotates the tracks under the laser and the result is a stream of serial data that can be transferred to a processor for interpretation.

ZEN proposed multibeam technology[1] to increase the performance of an optical drive. Multibeam technology provides for reading and processing multiple data tracks simultaneously. It multiplies the data transfer rate by the number of beams in use compared to single-beam technology under the same motor rotation speed. Combined with constant linear velocity (CLV) rotation system for constant rates across the whole disc, a multibeam drive is a so-called TrueX drive.

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Rather than directing a single laser beam at a single track of serial data on a disc, a multiple beam optical head creates multiple focus points that illuminate multiple tracks and reads their data in parallel. Other than the multiple beam optical head and controller electronics, there is no substantial change in a multibeam system. The mechanical elements and disc media are identical with standard drives. Fig. 1 shows the conceptual drawing of two kinds of optical heads. It is seen that the only differences between a conventional single-beam optical head (Fig. 1(a).) and a multiple-beam optical head (Fig. 1(b).), are that a multiple-beam grating[2] is placed in front of the laser for splitting the laser light into multiple diffracted beams and a multiple-beam detector array is positioned in the returning optical path for generating servo and data signals. The diffracted multiple beams pass through a beam splitter to the objective lens and are focused into multiple spots on the disk. The spots are uniformly spaced and illuminate multiple tracks. Focus and tracking are accomplished with the central beam with the same techniques used for a single-beam optical head. The beams reflected from the data tracks via the same optical path are directed to the multiple detecting regions that are spaced to align with multiple reflected tracks. A conventional central detecting region, e.g. a quad detector, is also provided for focus and tracking.

Holographic optical head modules combine the source, photodetectors, beamsplitter, and servo generating optical element(s) into a single package[3]. Many examples of holographic pickup-head modules have been developed. Besides the advantages of cost reduction in packaging the components and the compactness of the unit, one of the biggest advantages is modularity. Pickup heads can be flexibly designed to meet the mechanical and system needs of a variety of drive designs and the holographic module, which contains a significant portion of the optical system, can be plugged in almost as an afterthought. It's quite common in current commercialized single-beam optical head designs to plug in a holographic module to comprise the bulk of the optical system. Fig. 2 shows the basic construction of a holographic single-beam optical head. It can be easily extended to a holographic multiple-beam optical head.

Despite the advantages stated above, there are some drawbacks to using a holographic module in existing pickup-heads. The biggest problem is the low light utilization. The returning power incident on the photodetectors of a holographic module is around 1/3 - 1/12 that of a conventional pickup-head. This increases the loading of the current-to-voltage preamplifiers and can reduce the signal-to-noise ratio. Moreover, using a holographic module for a multiple-beam pickup-head increases the severity of the efficiency problem since a multiple-beam grating and holographic optical element (HOE) split the laser power into an even greater number of diffraction orders, many of which go unused in either the forward or returning light paths. In this paper, we avoid the efficiency problem of the holographic pickup head by using a polarization-selective diffractive optical element (DOE)[4,5]. An interesting polarization-selective DOE design is proposed that both increases the round-trip light efficiency and, at the same time, combines three functions (beamsplitter, servo signal generating, and multiple-beam grating) into a single optical element. With this design, a more compact, lightweight and high performance holographic multiple-beam pickup can be realized.

2. DESIGN CONCEPT

Fig. 3 shows the physical operation of a polarization diffractive element. The pattern is etched on a birefringent substrate with the indices n_o and n_e corresponding to ordinary and extraordinary waves respectively. The etched surface of the birefringent substrate is refilled with an isotropic material having index equal to n_o (or n_e). Consider the case of incident light with polarization aligned perpendicular to ordinary wave. The incident light will be phase modulated due to the difference between the extraordinary index of the birefringent material and the index of the isotropic backfill material and be diffracted by the etched pattern. In the other case, with the incident light polarization aligned along the ordinary index of the birefringent material, the light will experience no diffraction since the backfill material and is index-matched to the ordinary index and therefore the light doesn't see the grating.

The key idea of our polarization-selective DOE design uses two pieces of polarization elements. One element is designed as a multiple beam grating and the other is designed to function as a beamsplitter and servo-generating element. These two pieces are designed to diffract light of orthogonal polarizations. This can be implemented by rotating one piece of the polarization element by 90 degrees relative to the other and therefore interchanging the ordinary and extraordinary axes of the birefringent material in both elements. As shown in Fig. 4, by proper orientation of the diffractive patterns on two polarization elements, linearly polarized light travelling from the laser towards the disc is diffracted into multiple beams by the first grating surface, while experiencing no diffraction from the second. Travelling the roundtrip from the DOE to the disc and back to the DOE, the light traverses a quarter-wave retarder two times so that the return-trip light incident on the DOE is now linearly polarized perpendicular to that of the light coming from the laser. This light is now polarized such that it will be diffracted by the beamsplitter/servo-generating diffractive surface and experiences no diffraction from the multibeam grating surface. The light is steered onto the photodetectors and, at the same time, conditioned to create useful focus and tracking error signals.

In a holographic multiple-beam pickup-head, the multiple-beam grating is used only on the forward light path, while the beamsplitter/servo-generating element is used only on the returning path. With this polarization-selective DOE design, the two polarization elements are orthogonally oriented. Whether on the forward or the returning path, the laser beam will be diffracted by only one of the two elements. In this way, this design avoids wasting laser power in unwanted diffraction orders thereby increasing the light utilization efficiency. This is necessary to make a holographic multiple-beam pickup head feasible.

Fig. 5 compares various types of optical system designs with regards to the losses of grating and beamsplitter for multiple-beam optical heads. The efficiency calculation shown in Fig. 5(a) and Fig. 5(b) is for conventional type pickup-head design. Fig. 5(a) uses a common beamsplitter and has 50% of the light is lost in each direction. The multiple-beam grating is usually designed to evenly distribute 90% of incident light into the useful diffracted beams. This grating can be designed according to Dammann's method[6]. Fig. 5(b) uses a comparatively expensive polarization beamsplitter combined with a quarter wave plate and gains the highest roundtrip efficiency of 90%. It is four times the efficiency of Fig. 5(a). Fig. 5(c) and Fig. 5(d) are optical designs with holographic beamsplitters. Fig. 5(c) adapts the general structure common to holographic pickup heads to the multibeam case. It is seen to be the least efficient with only 2.2% roundtrip efficiency. This is why a standard holographic module for multibeam is impractical. Fig5d shows the design utilizing the proposed polarization-selective DOE element. The beamsplitter/servo-generating diffractive surface can be etched with either binary or blazed shape giving efficiencies of 40% or 96% respectively. The total roundtrip efficiency in Fig. 5(d) is estimated to be around 36~86%. It is better than Fig. 5(a) and Fig. 5(c).

The polarization-switched DOE can be constructed as a sandwich of two pieces of some birefringent material, as shown in Fig. 6, with one rotated by 90 degrees relative to the other so that the ordinary and extraordinary axes are interchanged, and with a common index-match layer between them. The index-match layer is a kind of isotropic material with index equal to that of either ordinary wave or extraordinay wave in the two birefringent pieces. Multiple-beam grating and HOE patterns are etched into each of the two birefringent pieces. This sandwich structure provides the same functions as that described in Fig. 4, combines two diffractive elements into a single piece and furthermost reduces the size of holographic optical module. An alternative method is to attach the quarter-wave plate on the sandwich polarization-switched DOE and make the system even more simplified. These compound polarization selective DOEs should be manufacturable at low cost with simultaneous fabrication of many pieces on a single substrate as is characteristic of DOEs.

3. CONCLUSION

In conclusion, we have introduced a method for constructing a holographic multiple-beam optical head. A polarization-switched DOE is proposed for avoiding the severe power losses in a holographic pickup head. The efficiency analysis gives a promising result. A sandwich-like structure is implemented for this polarization-switched DOE. With these designs, a high performance, compact size and lightweight multiple-beam optical pickup head can be achieved.

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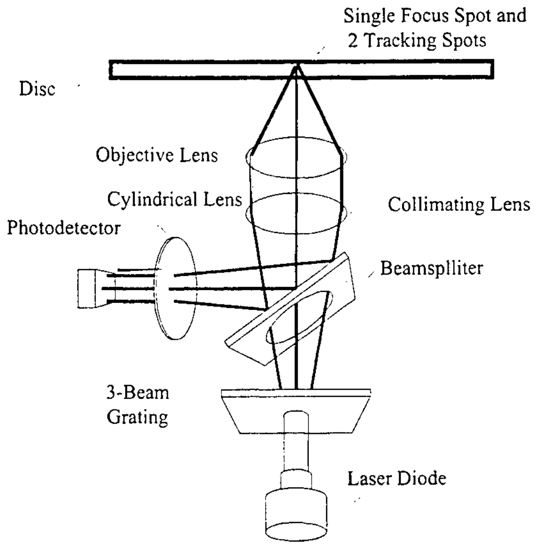
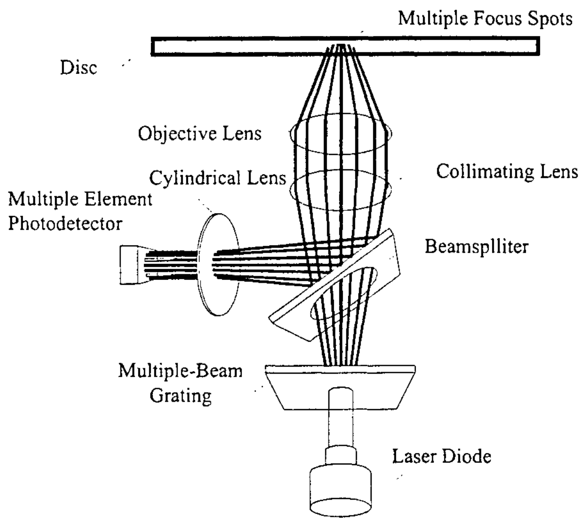


(a) Single-beam type



(b) Multiple-beam type

Fig. 1: Conventional optical pickup-head structure

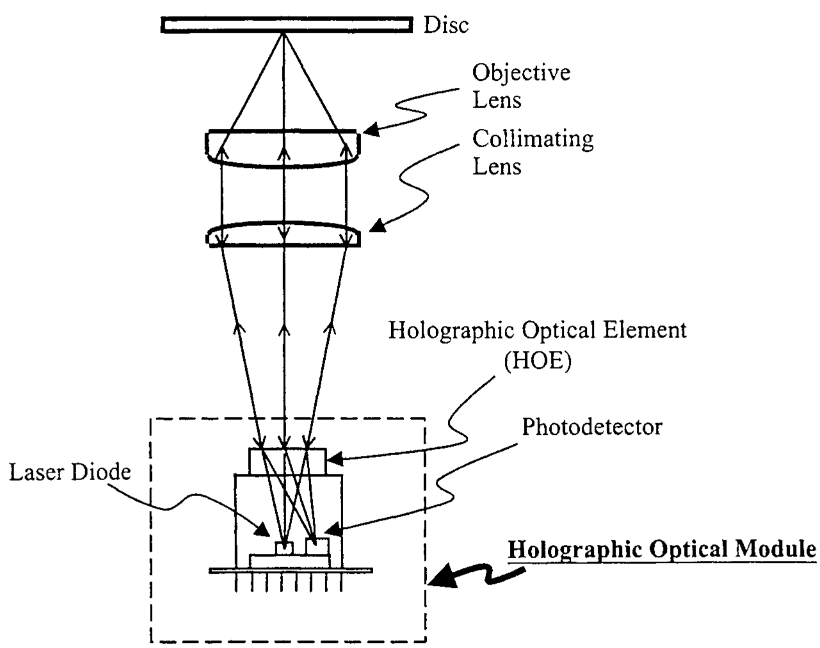


Fig. 2: Structure of a common holographic optical pickup-head

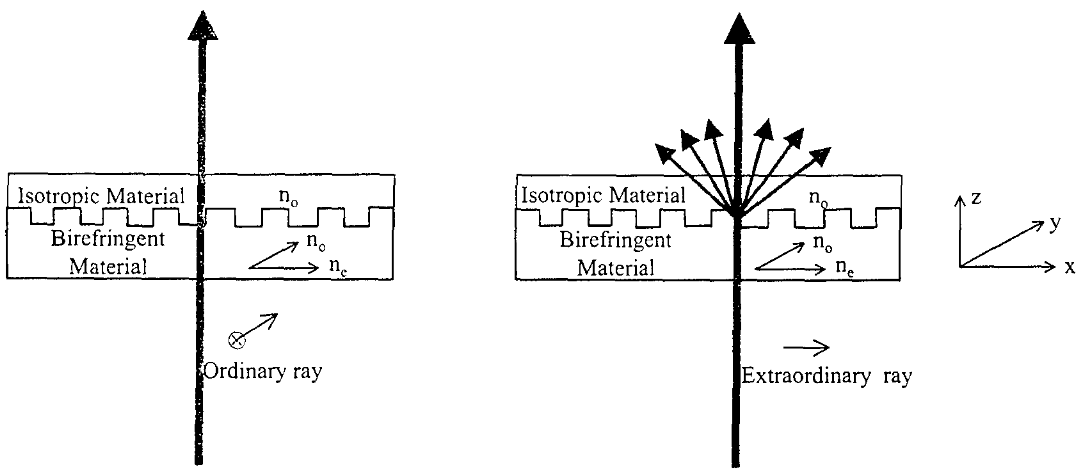
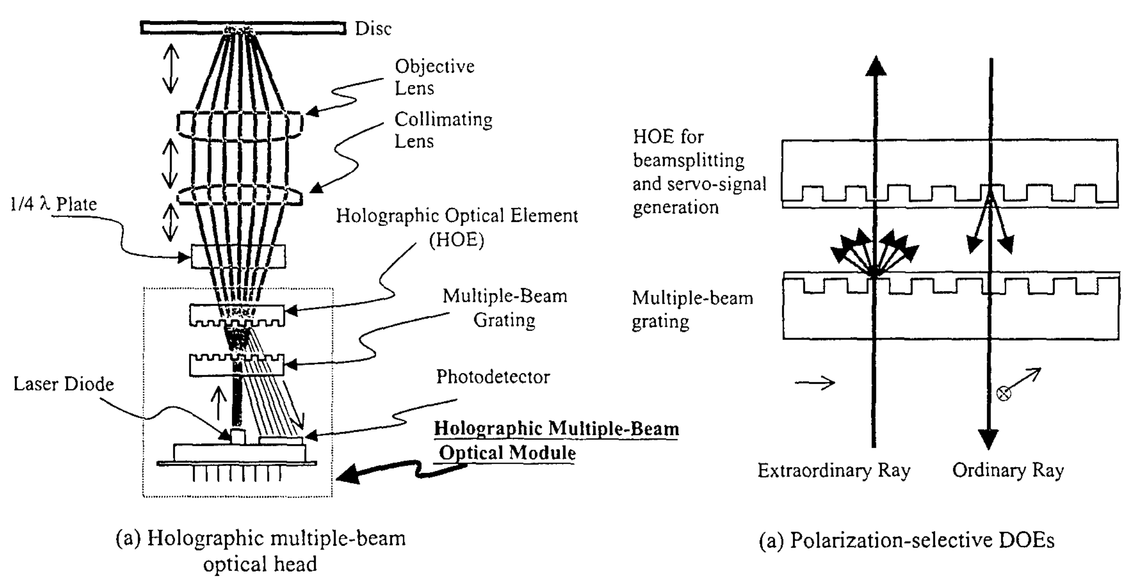


Fig. 3: The operation of a polarization-selective diffractive element



(a) Holographic multiple-beam optical head

(a) Polarization-selective DOEs

Fig. 4: The structure of a holographic multiple-beam optical head and polarized-switched DOE

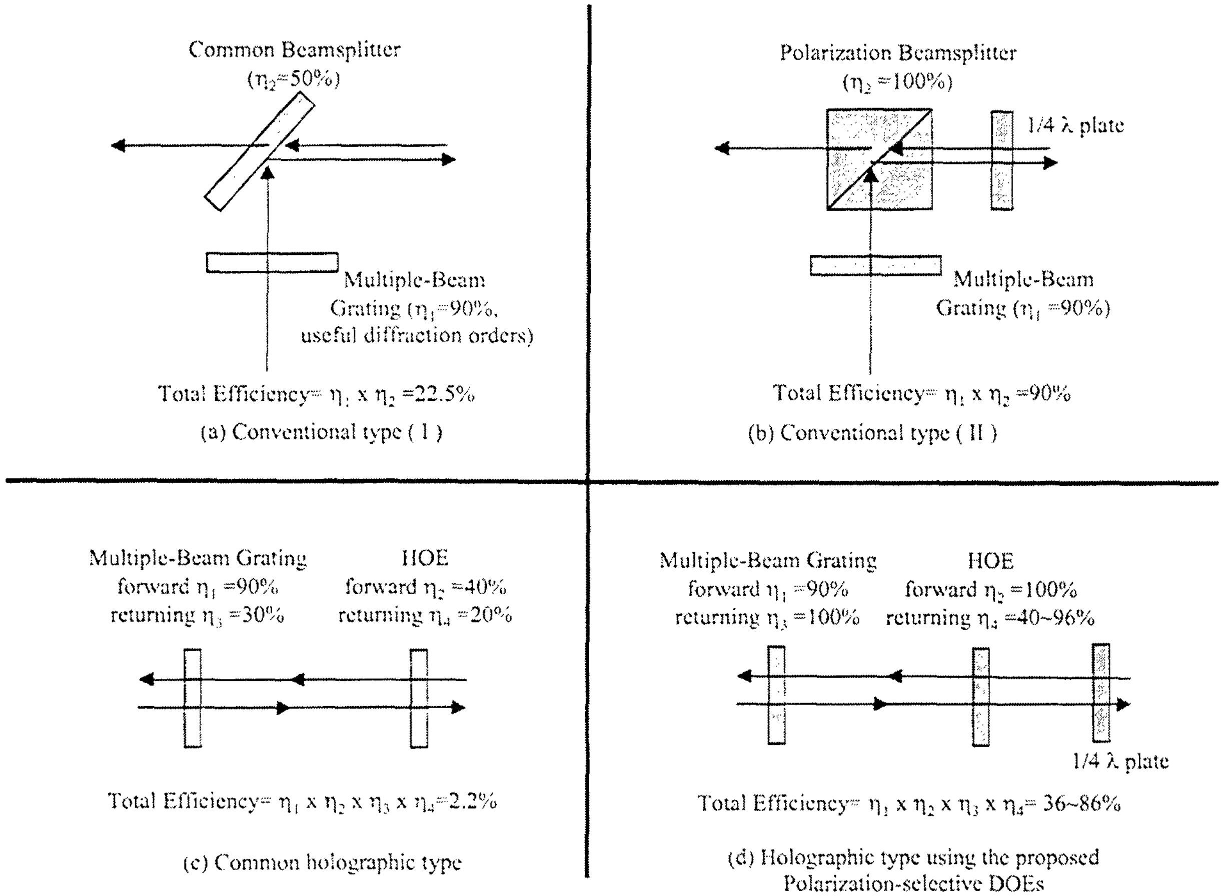
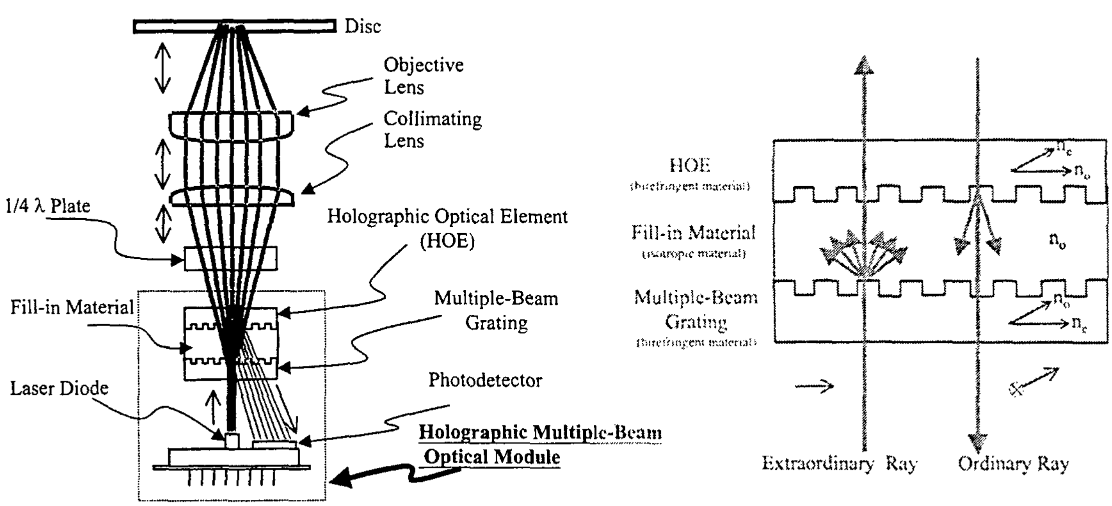


Fig. 5: Efficiency considerations for various types of multiple-beam optical head.



(a) Holographic multiple-beam optical head with sandwich DOE

(a) Sandwich-like Polarization-selective DOE

Fig. 6: The structure of a holographic multiple-beam optical head that uses a compact sandwich-like polarized-switched DOE